Effects of Cloud Microphysics on Tropical Atmospheric Hydrologic Processes and Intraseasonal Variability

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(Manuscript accepted 13 August 2004, in final form 30 May 2005)

ABSTRACT

The sensitivity of tropical atmospheric hydrologic processes to cloud microphysics is investigated using the NASA Goddard Earth Observing System (GEOS) general circulation model (GCM). Results show that a faster autoconversion rate leads to (a) enhanced deep convection in the climatological convective zones anchored to tropical land regions; (b) more warm rain, but less cloud over oceanic regions; and (c) an increased convective-to-stratiform rain ratio over the entire Tropics. Fewer clouds enhance longwave cooling and reduce shortwave heating in the upper troposphere, while more warm rain produces more condensation heating in the lower troposphere. This vertical differential heating destabilizes the tropical atmosphere, producing a positive feedback resulting in more rain and an enhanced atmospheric water cycle over the Tropics. The feedback is maintained via secondary circulations between convective tower and anvil regions (cold rain), and adjacent middle-to-low cloud (warm rain) regions. The lower cell is capped by horizontal divergence and maximum cloud detrainment near the freezing–melting (0°C) level, with rising motion (relative to the vertical mean) in the warm rain region connected to sinking motion in the cold rain region. The upper cell is found above the 0°C level, with induced subsidence in the warm rain and dry regions, coupled to forced ascent in the deep convection region.

It is that warm rain plays an important role in regulating the time scales of convective cycles, and in altering the tropical large-scale circulation through radiative–dynamic interactions. Reduced cloud–radiation feedback due to a faster autoconversion rate results in intermittent but more energetic eastward propagating Madden–Julian oscillations (MJOs). Conversely, a slower autoconversion rate, with increased cloud radiation produces MJOs with more realistic westward-propagating transients embedded in eastward-propagating supercloud clusters. The implications of the present results on climate change and water cycle dynamics research are discussed.

1. Introduction

Recently, there has been a growing body of evidence indicating the importance of tropical warm rain processes in the organization of tropical convection, modulation of clouds and rain types, and possibly global warming. Using 3 yr of data from the Tropical Rainfall Measuring Mission (TRMM), Short and Nakamura (2000) found that more than 20% of the total rain from the Tropics is derived from shallow convection. Johnson et al. (1999) showed that approximately 28% of the rainfall during the Tropical Ocean Global Atmosphere Couple Ocean–Atmosphere Research Experiment (TOGA COARE) may be accounted for by warm rain from midlevel *cumulus congestus*, and pointed to the importance of a midtropospheric inversion layer, formed by the melting of ice-phase precipitation falling from above, in limiting the growth of penetrative deep convection. They proposed that a basic trimodal (high, middle, and low), rather than the commonly accepted bimodal (high and low), cloud distribution as a more realistic description of the tropical cloud system. They also pointed out the importance of the cumulus congestus in determining the adjustment time scale of convective cycles. Wu (2003) inferred from theoretical calculations that about 20% of the latent heating in the Tropics would be contributed by mid- to low-level condensation processes in order to maintain the observed moist static stability profile. Innes et al. (2001) demonstrated that significant improvement in the simulation of the Madden–Julian oscillation (MJO) can be achieved by increasing vertical resolution, which helps to better resolve the melting level in convection in the

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